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Mechanical and durability properties of marine concrete using fly ash and silpozz

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Abstract. This article reports the utilization of fly ash (FA) waste product from industry and silpozz which is an agro-waste from agriculture as an environmental friendly material in construction industry. The evaluation of strength and durability study was observed using FA and silpozz as a partial replacement of Ordinary Portland Cement (OPC). The studied parameters are compressive strength, flexural strength, split tensile strength and bond strength as well as the durability study involves the acid soluble chloride (ASC), water soluble chloride (WSC), water absorption and sorptivity. Scanning electron microscopy (SEM) and X-RD of selected samples are also done. It reveals from the test results that the deterioration factor (DF) in compressive strength is 4% at 365 days. The DF of split tensile strength and flexural strength is 0.96% and 0.6% at 90 days respectively. The minimum slip is 1mm and 1.1mm after 28 days of testing bond strength for NWC and SWC sample respectively. The percentage decrease in bond strength is 10.35% for 28 days SWC samples. The pre-cast blended concrete samples performed better to chloride diffusion. Modulus of elasticity of SWC samples are also studied.The water absorption and sorptivity tests are conducted after 28 days of curing.

Keywords: blended cement concrete; bond strength; fly ash; super plasticizer; silpozz; sorptivity

1. Introduction

The growth of concrete technology is completely based on its strength but not only that should be considered but the coarseness degree of various environmental circumstances to which concrete is being exposed for life long as should be considered and have given lot of importance. So, finally both compressive strength and its nature of durability are considered clearly at different design phase and its relationship also taken into account. While estimating the conditions of present structures, the durability of concrete is the most important consideration to be taken into account in designing new structures. Construction of concrete is gradually very cost effective as its durability has been higher so it's becoming one of the most complex things. When one understand the concrete's fundamental basic of durability, all starts finding new methods to increase its service life of all the new and upcoming structures. Concrete's long time durability potential is the key to

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knowledge as it consists of uncommon materials such as recycled aggregate and high silica aggregates with mineral admixtures. Concrete structures are constructed in urban and industrial regions which are highly polluted, aggressive chemical environments, destructive underground water in marine zone and a lot of unreceptive conditions where building materials are expected to be non-durable. The factors affecting durability are the types of concrete, depth of cover to reinforcement, site supervision and practice as well as severity of exposure conditions. Durability of concrete may be improved by utilizing industrial by-products which are possessing hydraulic and pozzolanic properties when replacing with OPC. Nowadays, the emerging area is the waste utilization of environmental by product materials such as fly ash (FA) and silpozz to improve concrete strength and durability in marine environment. In construction sectors there is an increasing trend for sustainable development and utilization of FA and silpozz as a supplementary cementitious material (SCM). FA is generated during the combustion of coal for energy production and recognized as an environmental pollutant. Silpozz is manufactured by burning of agro-waste rice husk in designed furnace in between 600° to 700℃. Rice husk is the outer covering of rice grains collected during the milling process and considered one of the main agricultural residues and creates environmental problems after disposal. Silpozz is a carbon neutral green product and to be used as a substitute of silica fumes or micro silica. The low replacement of silpozz with OPC improves the workability, strength and impermeable concrete as well as durable concrete against chemical attacks, abrasion and corrosion to reinforcement also the increase of compressive strength by 10-20%. Because of creating environmental problems, the utilization of FA and silpozz is very important in the active area of research.

Some of the researchers have reported the utilization of supplementary cementitious materials (SCM) to improve concrete properties in marine climate. Jena and Panda (2017) studied the strength and carbonation of marine concrete using FA and silpozz as a blended concrete which works better in marine environment. Jena and Panda (2015) studied the development of compressive strength in blended concrete made with silpozz which can be used as an effective substitute material of silica fume (SF) to improve the durability of marine structures. Panda and Prusty (2015) enhanced the strength properties using silpozz as a partial replacement of OPC. Anwar and Roushdi (2014) showed the properties of concrete containing PC, FA and SF as blended cements for improvements in concrete to resist environmental causes of deterioration. Anwar *et al*. (2013) concluded that the combinations of 15 to 25% of FA with 5 to 10% SF show satisfactory performance in both fresh and hardened concrete. The SF improves early age performance of concrete with FA continuously refining the properties of hardened concrete as it matures and the replacement of 35% of cement quantity with 25% FA and 10% SF increased the compressive strength by 20% at 180 days. Andrade *et al*. (2013) have done the modeling of chloride penetration into marine concrete after conducting the accelerated chloride migration test. Yildirim *et al*. (2011) analyzed that the resistance of concrete against chloride diffusion depends on the different types cement and the compressive strength. The results indicated that the concrete having blast-furnace slag showed the highest resistance against chloride penetration compared to normal PC and sulfate resisting cement. Wegian (2010) investigated the strength properties including bond strength of concrete mixing and curing with sea water and the reduction in strength is directly proportional to exposure time due to the formation of the crystallization of salts. Shen *et al*. (2016) found that the slip corresponding to bond strength decreases with increase in compressive strength at early age. Sunil (2009) investigated the strength reduction factor on plain and cement concrete blended with FA were exposed to seawater attack for one year curing period. The results of this study showed that pre-cast concrete samples were better resistance against sea

Table 1 Physical properties of OPC

Characteristics	Experimental value	Value confirming to IS 8112:1989
Setting time (minutes)		
Initial setting time	165	30 (min)
Final setting time	360	600 (max)
Standard consistency (%)	34	NA
Specific gravity	3.15	3.15
Compressive strength (MPa)		
(a) 3 days	28 MPa	23 MPa
(b) 7 days	42 MPa	33 MPa
(c) 28 days	48 MPa	43 MPa
Fineness (m^2 / kg)	333	225 (min)

Table 2 Properties of aggregates

Specifications	Experimental value as per IS : 383-1970	
	Coarse aggregates	Fine aggregates
Fineness modulus	7.0	3.03 (Zone-3)
Specific gravity	2.86	2.67
Water absorption (%)	0.2	0.4
Bulk density (kg/m^3)	1424	1568
Abrasion value (%)	34.78	-
Impact value (%)	24	-
Crushing value (%)	23.3	-

water than the cast in-situ samples. Aburawi and Swamy (2008) reported the effects of salt weathering and curing conditions on the properties of high durability concretes containing chlorides. Aggrawal and Siddique (2014) studied the micro structural properties of concrete by analyzing the factors that influences the mechanical behavior of concrete such as size and shape of the particles, concentration and orientation of particles and distribution of particles as well as topology of cement concrete matrix using scanning electron microscopy. Bai *et al*. (2002) studied the sorpitivity and compressive strength for ternary blended concrete system on the development of high- performance concrete. Claisse (1997) framed a model for water absorption and sorptivity which showed good agreement with the experiment results. Dias (2000) experimented the sorptivity test on existing structures of 4 years and 3.5 years and observed that the rate of sorptivity decreases with exposure time.

This paper focuses the strength and durability study of pre-cast SWC concrete with FA and silpozz for different curing periods and the utilization of waste by-product such as FA and silpozz which creates environmental problems after disposal.

2. Experimental program

2.1 Properties of materials used

Table 3 Physical property of FA and Silpozz

Physical properties	FA	Silpozz
Specific gravity	2.12	2.3
Bulk density (gm/cc)	1.2	0.23
Specific surface, m^2/g	33	17
Particle size (Micron)	34	25
Color	Gray	Gray black
Physical state	-	Solid Non-hazardous

Table 4 Chemical composition of cementitius materials

Oxides (%)	Cement (OPC)	Silpozz	FA
SiO_2	20.99	88.18	58.13
Al_2O_3	6.05	1.61	31.00
Fe_2O_3	6.01	0.56	4.10
Carbon	-	2.67	-
CaO	62.74	1.59	0.60
MgO	1.33	1.63	0.10
K_2O	0.40	1.67	0.90
Na_2O	0.04	-	0.05
SO_3	1.82	-	0.12
TiO_2	.025	-	1.63
Others	-	2.09	0.011
Moisture content (%)	-	0.79	3.0
Loss on ignition (%)	1.14	0.04	0.29

In this work, OPC 43 grade, FA, Silpozz, fine aggregate, coarse aggregate, normal water, sea water and SP are used in this study. The physical test properties of OPC confirming to IS 8112:1989 are shown in Table 1. The experimental value of aggregates confirming to IS: 383-1970 is presented in Table 2. CERA HYPERPLAST XR-W40 high end SP is used. FA is a fine material and possesses good pozzolanic activity. Silpozz can be used as an effective mineral admixture to make special concrete mixes and also improves the durability of marine concrete. The heat of hydration is lowered by as much as 30% when silpozz is added to concrete, as well as prevents formation of cracks during casting. The physical and chemical compositions of FA and silpozz given by the supplier are shown in Tables 3-4.

2.2 Mix proportions and identifications

Usually in marine concrete silpozz can be used as an effective material to make a relatively richer concrete mix. Considering this point the minimum grade of concrete is M30 which is suitable for marine environment and designed as per Indian Standard code 10262-2009. The obtained material ratio was (1: 1.44: 2.91), w/b 0.43. The controlled specimen is prepared with 100% OPC without SP and there is no change of quantity of materials. As SP is used in blended concrete mixes, the amount of water was reduced by 20% based upon the several trial mixes in order to maintain the slump in between 25-50 mm. The first blended concrete samples were made 0% FA and the silpozz replacement varied from 10-40% with OPC. The second blended concrete samples were made 10% FA and the replacement of silpozz varied from 10-40% with OPC. The third blended concrete samples were made 20% FA and replacement of silpozz varied from 10-30% with OPC. The fourth blended concrete samples were made 30% FA and silpozz varied from 10-20% with OPC. The details of mix identity along with doses of SP are given in Table 5. The materials were batched into the mixer according to the following sequence: coarse aggregate followed by sand, and then cementitious materials (OPC, FA and Silpozz were well mixed outside the mixer).The total mixing time was three minutes divided into two stages, starting with 60 s dry mixing, followed by the addition of the required water within 30s, then the mixer continued for the next 1.5 min of wet mixing and after adding SP the mixture continued for extra 1.5 to 2 min for wet mixing. The doses of SP were added to the silpozz based samples of 10-40% replaced with OPC. After casting, the concrete moulds were compacted by a vibrator. The samples were finished, stripped from their moulds the day after casting. The specimens were cured in water until testing. Workability of fresh concrete was measured by slump test and compaction factor test just after mixing. It was observed that the slump value varied between 34 to 42 mm and the compaction factor varied between 85.00 to 96.00%. The details of concrete mix quantities in kg/m^3 along with slump value and compaction factor are shown in Table 6.

2.3 Specimen preparation and curing condition

Standard concrete cubes of size 150 mm × 150 mm× 150 mm were used for measuring the compressive strength. For the split tensile strength the concrete cylinders of size 100 mm diameter and 200 mm height were taken and concrete beams of size 100 mm × 100 mm × 500 mm were employed for determination of flexural strength. The compressive strength was determined for cube samples after 7, 28, 90, 180 and 365 days of NWC. The flexural and split tensile strength was tested at the age of 7, 28 and 90 days of NWC for the samples of prism and cylinder respectively.

Table 5 Details of cementitious materials with SP

Mix Identity	Cement (%)	FA (%)	Silpozz (%)	SP (%)
MC100F0S0	100	0	0	-
M1C90F0S10	90	0	10	0.20
M1C80F0S20	80	0	20	0.29
M1C70F0S30	70	0	30	0.40
M1C60F0S40	60	0	40	0.60
M1C80F10S10	80	10	10	0.22
M1C70F10S20	70	10	20	0.33
M1C60F10S30	60	10	30	0.47
M1C50F10S40	50	10	40	0.72
M1C70F20S10	70	20	10	0.25
M1C60F20S20	60	20	20	0.38
M1C50F20S30	50	20	30	0.56
M1C60F30S10	60	30	10	0.30
M1C50F30S20	50	30	20	0.46

Table 6 Details of mix quantity with slump value and compaction factor (%)

Mix Identity	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	FA (kg/m^3)	Silpozz (kg/m^3)	Water	SP (kg/m^3)	Slump (mm)	Compaction factor (%)
MC100F0S0	434.32	624.77	1264.97	0	0	186.76	-	35	83.00
M1C90F0S10	390.88	624.77	1264.97	0	43.44	149.40	0.781	34	85.00
M1C80F0S20	347.45	624.77	1264.97	0	86.86	149.40	1.005	38	90.00
M1C70F0S30	304.00	624.77	1264.97	0	130.33	149.40	1.229	40	92.00
M1C60F0S40	260.60	624.77	1264.97	0	173.72	149.40	1.564	41	94.00
M1C80F10S10	347.45	624.77	1264.97	43.44	43.44	149.40	0.781	37	86.00
M1C70F10S20	304.00	624.77	1264.97	43.44	86.86	149.40	1.005	42	96.00
M1C60F10S30	260.60	624.77	1264.97	43.43	130.33	149.40	1.229	40	92.00
M1C50F10S40	217.16	624.77	1264.97	43.44	173.72	149.40	1.564	41	94.00
M1C70F20S10	304.00	624.77	1264.97	86.86	43.44	149.40	0.781	37	86.00
M1C60F20S20	260.60	624.77	1264.97	86.86	86.86	149.40	1.005	38	90.00
M1C50F20S30	217.16	624.77	1264.97	86.86	130.33	149.40	1.229	41	92.00
M1C60F30S10	260.60	624.77	1264.97	130.33	43.44	149.40	0.800	34	86.00
M1C50F30S20	217.16	624.77	1264.97	130.33	86.86	149.40	1.005	38	92.00

The compressive strength was determined for second group of samples consists of cubes at 7, 28, 90, 180 and 365 days of SWC after 28 days of NWC. Similarly, the flexural and split tensile strength was tested at 7, 28 and 90 days of pre-cast samples. The specimen size for pull out test is 150 mm×150 mm×150 mm with a reinforcing tor bar of 12 mm diameter. Total length of the bar is 120 mm with a bond length of 60 mm. For all specimens the load rate was 0.1 kN/s. The types of failure were identified for each test by recording the bond strength after 28 days of NWC and SWC pre-cast samples. The slip results measured at the free end with a dial micrometer an accuracy of 0.0025 mm. The WSC and ASC were measured at 28, 90, 180 and 365 days for pre-cast SWC specimens.

2.4 Mineralogical characterization of the FA and silpozz

The mineralogical characterizations of the FA and silpozz samples were carried out by *X*-Ray Diffraction (XRD) study by using a Cu target *X*-Ray diffractometer. The different mineral phases were identified by comparing the d-spacing which is given in ASTM data cards and shown in Fig. 1 and Fig. 2 respectively. Although the FA samples are composed of glassy material, several peaks were observed and the minerals are identified quartz low, hematite or iron oxide. Phase analysis of silpozz by XRD indicates the presence of quartz low and silicon dioxide. Silpozz contains amorphous silica which is produced from rice husk burning in a controlled temperature below 700℃. This ash produced is amorphous in nature. Due to amorphous in nature, small peaks were observed and the minerals are quartz low and silicon dioxide. The amorphous state transforms to crystalline state when the ash is exposed to high elevated temperatures of above 850℃. Their crystalline structure is unknown by XRD due to amorphous in nature. It has been reported by Agarwal (1989) that at low temperature (599.85℃-699.85℃) silica in rice husk ash (RHA) is amorphous, and crystallization occurs when temperature goes above 699.85℃.

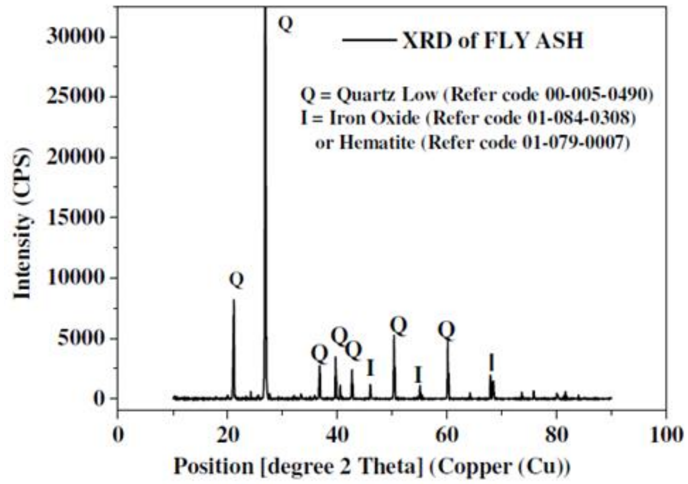

Fig. 1 *X*-ray diffraction of fly ash

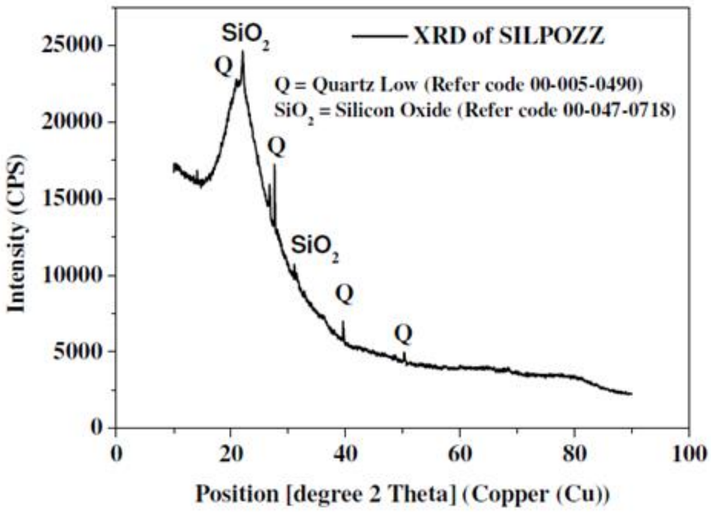

Fig. 2 *X*-ray diffraction of silpozz

3. Results and discussions

3.1 Properties of fresh concrete

Workability is defined as “that property of freshly mixed concrete or mortar that determines the ease with which it can be mixed, placed, consolidated and finished to a homogenous mass” (ACI Committee 116). The measured values of slump and compaction factors are listed in Table 6 and they fall within the designed range.The dose of SP was added only to maintain the slump in between 25-50 mm and the experimented slump ranged from 34 to 42 mm was observed. It was found that in 0% FA concrete, the dose of SP increases from 0.20%-0.60% as the silpozz replacement ratio is from 10%-40% with OPC respectively. The dose of SP is also increased from

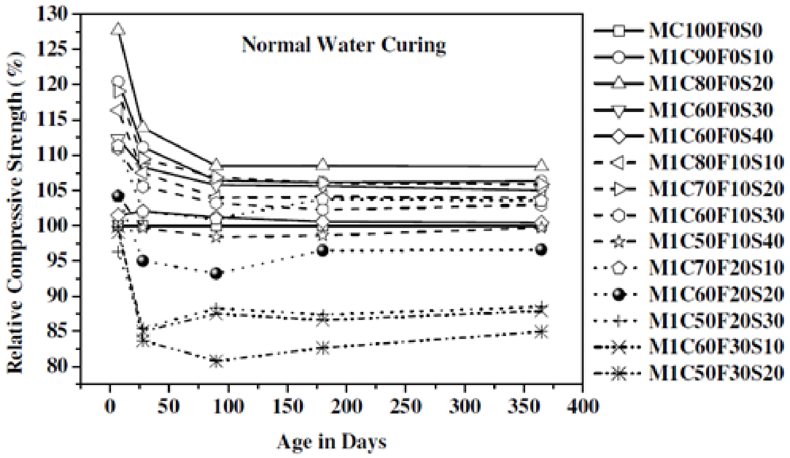

Fig. 3 Relative compressive strength versus age in days (NWC)

0.22%-0.72% in 10% FA concrete and 10%-40% silpozz replaced with OPC respectively. From the above study it reveals that the doses of SP increased as the silpozz content increased and it is also reported by Shannag (2000) that the higher replacement of SF is often accompanied by the use of SP. There is no sign of bleeding and segregation of concrete. The compaction factor ranges from 85.00 to 96.00% which shows good workable concrete at all levels.

3.2 Properties of hardened concrete

The strength properties are compressive strength, split tensile strength and flexural strength was determined confirming to IS 516-1959. The compressive strength was tested at 7, 28, 90, 180 and 365 days of NWC and SWC samples after 28 days NWC. The split tensile strength and flexural strength was tested at 7, 28 and 90 days of NWC and SWC samples after 28 days NWC. The bond strength was conducted after 28 days of NWC and SWC pre-cast samples.

3.2.1 Compressive strength

The average compressive strength was reported by taking the test results of at least three samples. The compression test results are presented in Table 7. The relative compressive strength versus age in days for NWC specimen is presented in Fig. 3. It is studied from the Fig. 3 that from all binary systems, the concrete containing 0% FA and 20% silpozz replacing with OPC contributes higher compressive strength after 7 days to 365 days than the control specimen. For the above sample, the rate of increment of compressive strength is 27.74% after 7 days, 13.88% after 28 days and 8.48%, 8.5% and 8.4% after 90, 180 and 365 days of NWC respectively than the control specimen. The compressive strength of mixes containing 10% FA fixed and silpozz 20% replaced with OPC contributes higher strength from all the ternary systems than the control specimen at all ages after NWC. The rate of increment of compressive strength for the above ternary system sample is 19%, 9.5%, 7%, 6% and 6% after 7, 28, 90, 180 and 365 days respectively than the control specimen. It is also observed from Fig. 3 that all silpozz based samples where FA is 0% showed higher compressive strength than the control specimen but in the ternary systems the compressive strength is higher for those mixes containing 10% FA fixed and

Table 7 Compressive strength of concrete mixes at different testing ages (MPa)

Concrete mix	Compressive strength of NWC (MPa)					Compressive strength of SWC after 28 days of NWC (MPa)				
	7	28	90	180	365	7	28	90	180	365
MC100F0S0	36.95	51.15	62.50	65.80	67.80	51.15	51.20	58.60	61.40	64.50
M1C90F0S10	44.50	56.85	66.50	69.85	72.10	55.80	62.25	65.05	66.20	68.50
M1C80F0S20	47.20	58.25	67.80	71.40	73.50	58.25	63.42	65.50	66.45	68.75
M1C70F0S30	41.50	55.40	66.10	69.50	71.20	55.40	61.00	63.50	65.10	67.70
M1C60F0S40	37.50	52.20	63.25	66.20	68.10	54.20	58.60	60.90	62.20	63.40
M1C80F10S10	43.00	55.00	65.00	68.50	70.50	55.10	61.40	64.50	66.10	68.80
M1C70F10S20	44.00	56.00	66.80	69.80	71.80	56.00	61.80	64.80	66.50	69.50
M1C60F10S30	41.00	54.00	64.50	67.30	69.80	52.00	57.00	61.20	63.80	64.80
M1C50F10S40	38.50	51.00	61.50	64.90	67.60	51.20	55.20	57.30	59.80	61.25
M1C70F20S10	41.15	52.20	63.10	68.30	70.20	52.20	56.80	53.50	52.50	48.80
M1C60F20S20	38.50	48.60	58.25	63.50	65.50	48.60	56.50	50.90	48.50	48.0
M1C50F20S30	35.60	43.70	55.20	57.50	60.00	43.70	55.10	50.04	48.20	47.60
M1C60F30S10	36.60	43.50	54.70	57.00	59.60	43.50	54.70	45.50	43.20	41.50
M1C50F30S20	34.80	42.82	50.50	54.50	57.60	42.82	52.60	39.40	36.20	34.00

10-30% silpozz replaced with OPC than the control mix at all ages and the mix with 20% FA and 10% silpozz also contributes slightly higher strength than the control specimen. The remaining samples showed less strength and falling below the control specimen which are shown in dotted lines in Fig. 3. Due to mixing of SP, The percentage increase in compressive strength for NWC samples having silpozz 20% fixed and FA 0%, 10% and 20% replaced with OPC is 27.74%, 19.07%, and 4.2% than the control mix without SP at 7 days respectively. The effect of SP is negligible for the sample 20% FA and 20% silpozz as the strength decreases after 28 days to 365 days than the OPC mix without SP. Even the higher dose of SP does not help to increase the early age strength to 365 days age for the sample 30% FA and 20% silpozz as compared to OPC mix without SP which is studied from Table 7. From the Fig. 3 it is observed that the ternary systems containing 10% FA fixed and upto 30% silpozz replacement with OPC falls above the control specimen line at all ages but the sample containing 10% FA fixed and 40% silpozz replacement with OPC falls just above the control specimen line at 7 days and from 28 days onwards it falls just below the control specimen though the dose of SP is higher among all the samples. The relative compressive strength versus age in days SWC pre-cast specimen is shown in Fig. 4. After 28 days NWC, the samples are immersed in sea water and it is studied that the 7 days compressive strength in SWC samples are more or less equal to the NWC 28 days samples which is presented in Table 7. It is observed that all silpozz based SWC samples with SP are above the control specimen line which indicates higher compressive strength than the control specimen. It is compared that the silpozz based sample containing 0% FA and 20% silpozz replaced with OPC including SP 0.29% contributes higher strength among all the samples in NWC but in SWC the rate of decrease in strength is 6.5% after 365 days as compared to NWC sample of same mix. AS the dose of SP is 0.33%, the percentage decrease in strength is 3.23% for ternary system containing 10% FA and 20% silpozz replaced with OPC as compared to NWC and SWC samples at 365 days. The study reveals that concrete with 10% FA and 20% silpozz with proper doses of

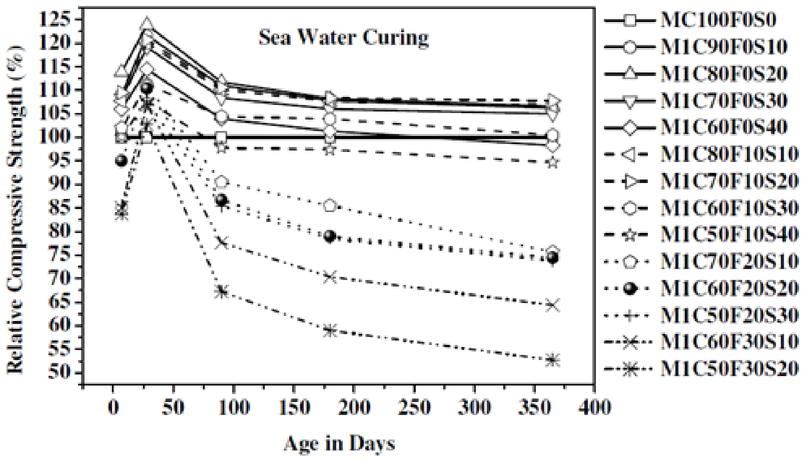

Fig. 4 Relative compressive strength versus age in days (SWC)

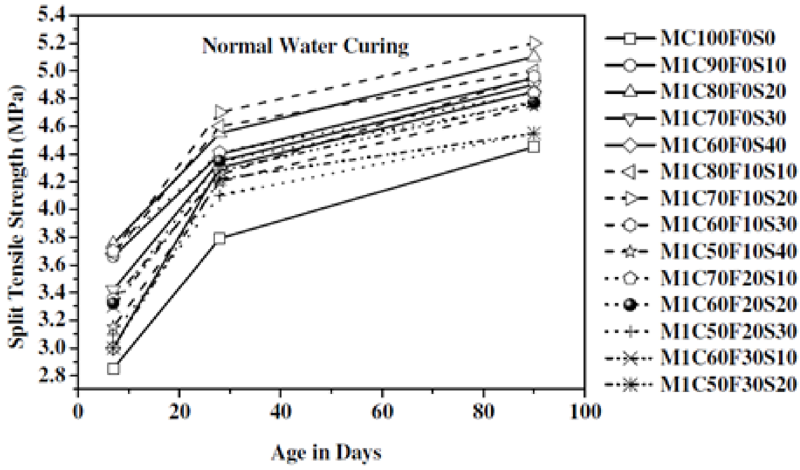

Fig. 5 Split tensile strength versus age in days (NWC)

SP contribute better resistance against sea water as compared to silpozz based samples having 0% FA and 20% silpozz replaced with OPC. The decrease in compressive strength is 3%, 4.72% and 3.2% for SWC pre cast sample M1C70F10S20 at 90, 180 and 365 days when compared to NWC specimen. Similarly the decrease in compressive strength is 3.4%, 7% and 6.5% for SWC pre cast sample M1C80F0S20 at 90, 180 and 365 days when compared to NWC specimen respectively. It reveals from above analysis that the combined action of FA and silpozz with doses of SP works better in sea water.

3.2.2 Split tensile strength

Cylinder samples of diameter100 mm and height 200 mm were tested for split tensile strength at the age of 7, 28 and 90 days for NWC and SWC samples after 28 days of NWC. The average split tensile strength was reported by taking the test results of at least three samples. The split tensile strength versus age in days for NWC samples is shown in Fig. 5. It is studied from Fig. 5

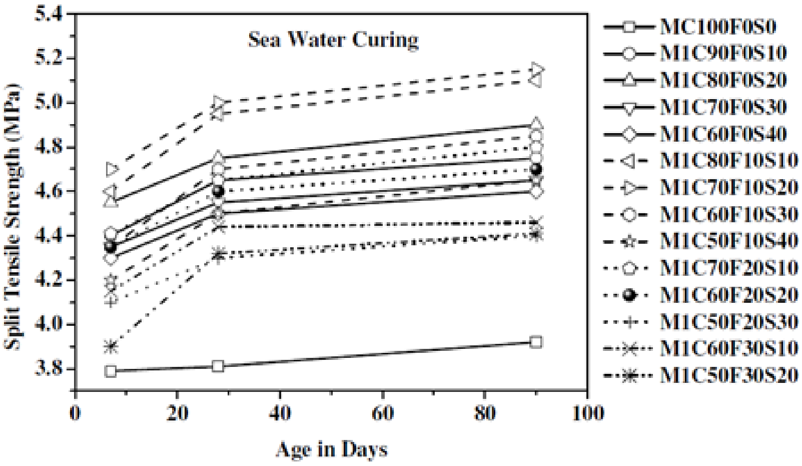

Fig. 6 Split tensile strength versus age in days (SWC)

that the sample containing 10% FA and 20% silpozz replaced with OPC contributes the highest split tensile strength than other NWC samples including control specimen and the rate of increment of split tensile strength is 24% and 16.85% at 28 and 90 days respectively. The percentage increase in split tensile strength for NWC blended concrete containing 0% FA and 20% silpozz replaced with OPC is 18.73% and 12.35% at 28 and 90 days age respectively as compared to control specimen. The percentage increase in split tensile strength is 28.77%, 29.82%, 16.49% and 0.35% at 7 days for the samples having 20% silpozz fixed and 0-30% FA replaced with OPC using SP than the control specimen without SP respectively. From the above analysis it is reported that as the percentage of FA increases the percentage increase in split tensile strength decreases even higher dose of SP is used at early age. The split tensile strength versus age in days for SWC samples are presented in Fig. 6, from which it is studied that the percentage decrease in split tensile strength is 1% for the SWC sample of 10% FA with 20% silpozz with 0.33% SP at 90 days as compared to NWC specimen but the SWC sample containing 0% FA and 20% silpozz with 0.29% SP shows the percentage reduction of split tensile strength is 4.82% than the NWC sample. It reflects that ternary system of concrete using SP is attaining proper resistance against sea water attack. Replacement of silpozz in concrete increases the early strength and later age strength is developing with 10% FA. Wei *et al*. (2004) studied that the addition of SF, slag and FA at the same time, SF starts early pozzolanic reaction which provides early strength and slag begins strong pozzolanic effect. After 28 days, FA also gradually provides its contributions to the strength of concrete at later age.

3.2.3 Flexural strength

The flexural strength was conducted on beam samples of size 100 mm×100 mm×500 mm for NWC and SWC samples after 28 days of NWC. In the ternary system of concrete containing 10% FA and 20% silpozz replaced with OPC shows the highest flexural strength and the percentage change in flexural strength at 90 days with respect to the control specimen is 44.82% for NWC samples and 49.10% for SWC samples. All silpozz based samples with 10% FA with SP are performing more flexural strength than the FA based samples at 7, 28 and 90 days of NWC and is given in Fig. 7. Flexural strength versus age in days for SWC samples is presented in Fig. 8. It is

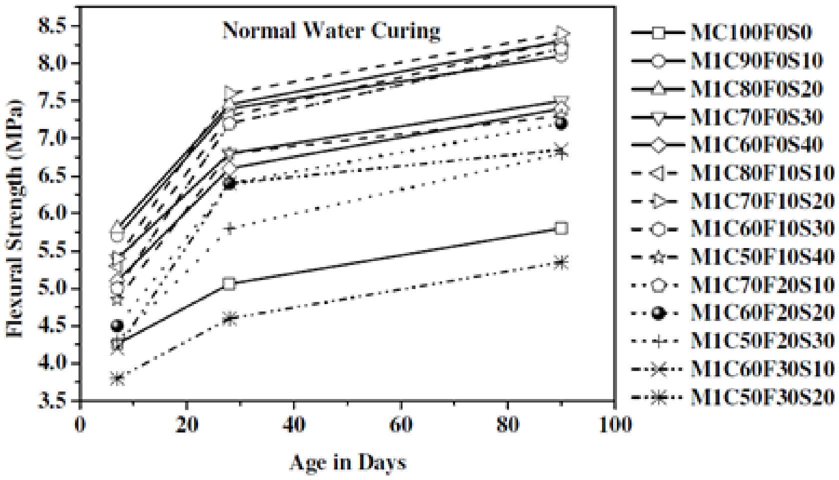

Fig. 7 Flexural strength versus age in days (NWC)

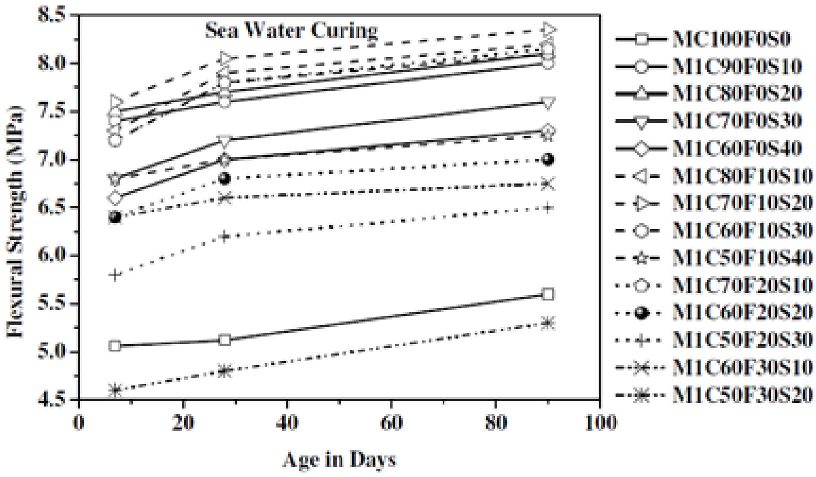

Fig. 8 Flexural strength versus age in days (SWC)

found from Fig. 7 that the samples having 10% FA and silpozz variable from 10 to 40% performed higher flexural strength than the FA based concrete and control specimen at all the ages. It is shown from Fig. 8 that the flexural strength of SWC samples are almost same at 28 days and deterioration takes place at 90 days age than the NWC samples. The rate of deterioration process increases as the percentage replacement of FA increases at 90 days age for SWC samples after 28 days of NWC. But due to mixing of SP the sample containing 10% FA and 20% silpozz replacement with OPC enhances the flexural strength upto 49.10% at 90 days for SWC samples after 28 days of NWC than control mix without SP. When compared with NWC sample, the rate of deterioration of flexural strength is 0.6% at 90 days age. For binary system of SWC samples containing 0% FA and 10%-40% silpozz replaced with OPC, the average percentage deterioration of flexural strength is 2% as compared to NWC samples at 90 days age. It indicates that the performance of ternary system containing FA and silpozz with proper doses of SP in sea water is better than the binary system with only silpozz which is also reported by Anwar *et al*. (2013).

3.2.4 Bond strength

The specimen size for pull out test is 150 mm×150 mm×150 mm with a reinforcing tor bar of 12 mm diameter. Total length of the bar is 120 mm with a bond length of 60 mm. For all specimens the load rate was 0.1 kN/s. The types of failure were identified for each test by recording the bond strength slip results measured at the free end with a dial micrometer an accuracy of 0.0025 mm. The ultimate bond strength was calculated from $\tau_b=F_{max}/\pi\Phi L$, Where τ_b is the bond strength, F_{max} is the maximum pull out force, Φ is the diameter of the tor bar and L is the bond length. The bond strength setup is shown in Fig. 9. The bond strength versus types of mix is shown in Fig. 9. It observed from Fig. 9 that the percentage decrease in bond strength is about 7% for sample of 10% FA and 20% silpozz replaced with OPC. The highest value of the percentage decrease in bond strength is 10% for control specimen at 28 days of curing. The combined samples having FA and silpozz performed better in sea water. The slip in ‘mm’ versus types of mix is shown in Fig. 10. It is observed from Fig. 10 that slip is limited to 1.2 mm for normal concrete and minimum slip is 1 mm for silpozz based concrete. Slip is mainly depends upon the bond between cement concrete matrix and steel reinforcement. It was noted at the time of maximum applied load. When FA is added with silpozz the slip is controlled and less than the control specimen. It was observed that slip corresponding to bond strength decreases as the compressive strength increases. It is observed that slip is same for the specimen having 0-20% FA and 10-30% silpozz replaced with OPC. The maximum slip is limited to 2.2 mm and 2.3 mm for NWC and SWC pre-cast specimen having 30% FA and 20% silpozz replaced with cement as compared to normal concrete. The sample 10% FA and 20% silpozz gives higher bond strength and compressive strength with minimum slip of 1 mm.

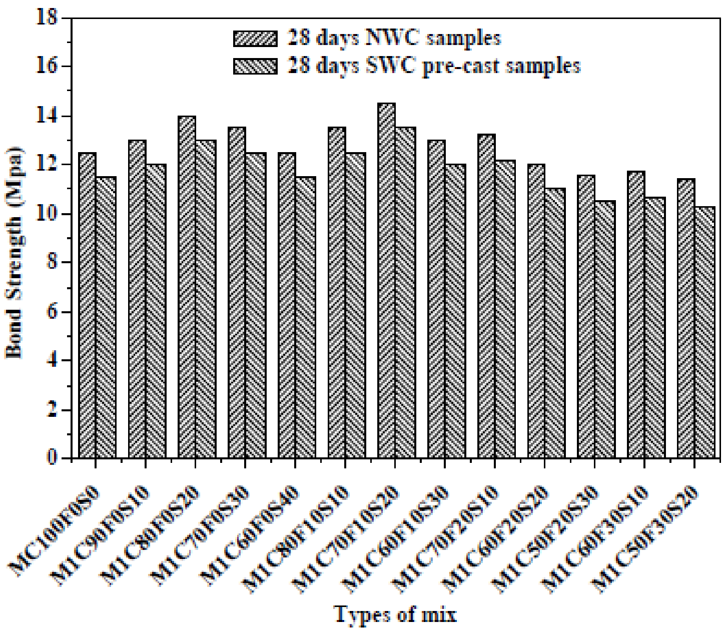

Fig. 9 Bond strength versus types of mix (NWC and SWC)

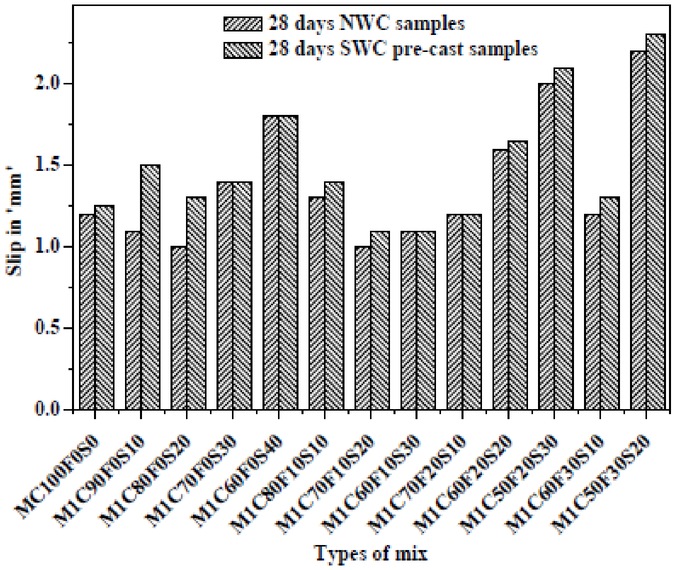

Fig. 10 Slip versus types of mix (NWC and SWC)

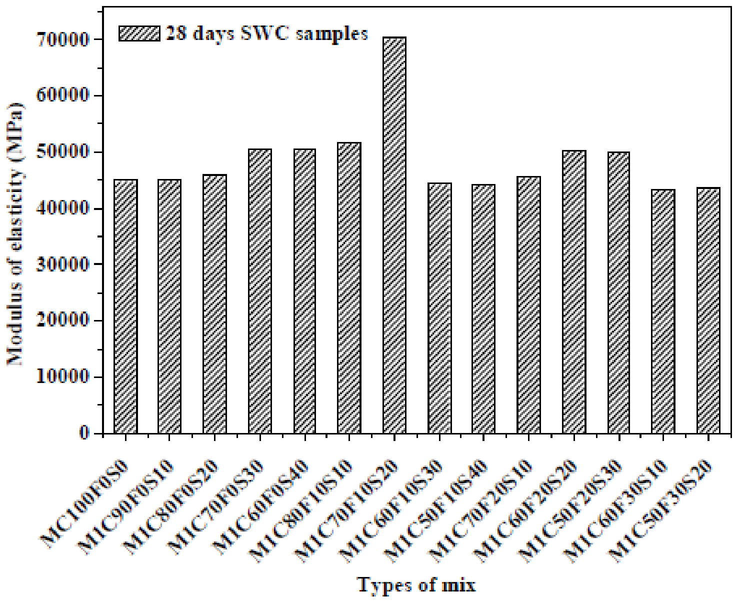

Fig. 11 Modulus of elasticity versus types of mix (SWC)

3.2.5 Modulus of elasticity

Modulus of elasticity is otherwise known as young's modulus of elasticity which is the function of concrete which reveals its elastic nature mainly of aggregate and cement paste in proper relative ratio. It is relatively constant with keeping its stress at a low point because it develops a crack in concrete paste at a level of higher stress. Modulus of elasticity concrete ranges from 30 to 50 GPa. Fig. 11 shows the modulus of elasticity (MPa) versus types of mix for 28 days SWC samples. The

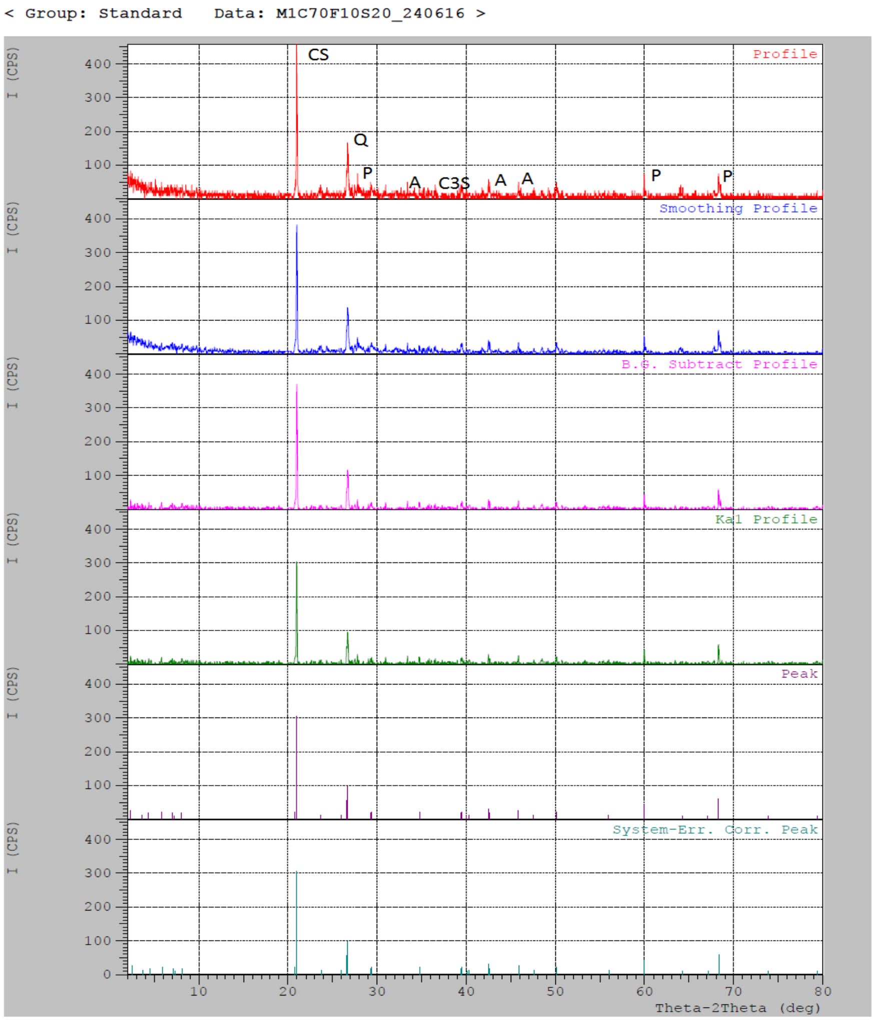

Fig. 12 XRD of specimen M1C70F10S20 (SWC)

sample containing 10% FA and 20% silpozz showing highest value of elasticity for the study. Silpozz based samples mixed with FA giving higher modulus of elasticity than the other samples after 28 days of SWC. There is no change upto 20% silpozz but suddenly modulus of elasticity increases when 10% FA and 20% silpozz replaced with OPC.

4. XRD of specimen M1C70F10S20

The mineralogical characterizations of the specimen M1C70F10S20 was carried out by *X*-Ray Diffraction (XRD) study by using a Cu target *X*-Ray diffractometer after 28 days of SWC which is shown in Fig. 12. The different mineral phases were identified by comparing the d-spacing which is given in ASTM data cards and indicate peaks of mineralogical characteristics of A: Albite, P: Portlandite, Q: Quartz, CS: Calcium Silica and C_3S: Tricalcium Silicate.

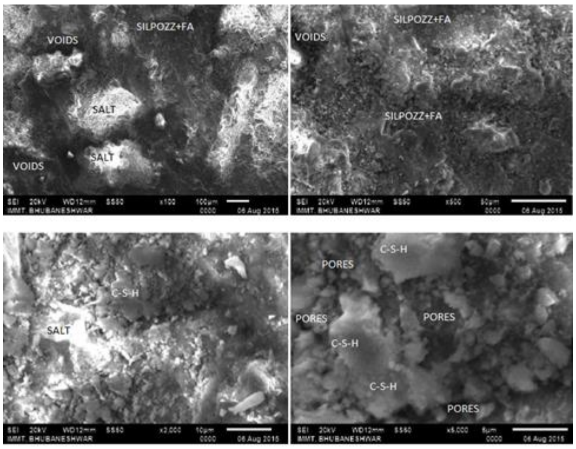

Fig. 13 SEM of NWC sample (M1C70F10S20)

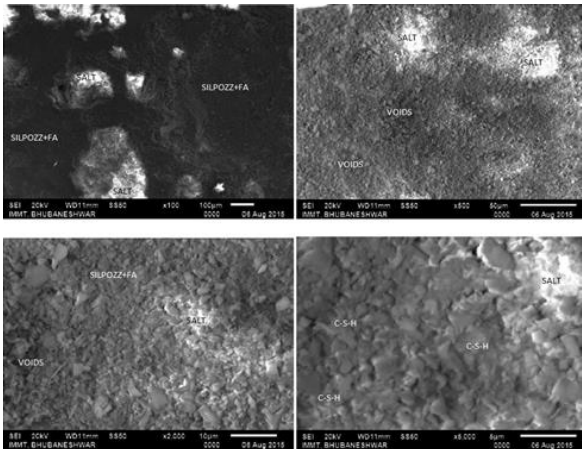

Fig. 14 SEM of SWC sample (M1C70F10S20)

5. Scanning electron microscopic studies

Since for many years, scanning electron microscopy (SEM) is acting as a basic tool for the researchers in the field of investigation for internal complexity of structural concretes and hydrated cement pastes. Various techniques such as transmission electron microscopy and petro graphic microscopy can be adopted to investigate the internal architecture. The factors affecting microstructure are the age of concrete, types of cement, water to binder ratio, heat treatment, replacement of chemical and mineral admixtures and many other variables. Furthermore deterioration takes place by various chemical and physical attacks in marine environment which can change their inner structures as well as their characteristics. Internal construction of cement concretes and properties within concretes are essential elements for a structural designer who deals with concrete properties and behaviour in service. SEM studies are essential for developing mathematical models and durability of concrete. SEM for the sample M1C70F10S20 is given in Figs. 13 and 14 both in NWC and SWC respectively. The phases of different SEM images are studied as per the literature available by Aggarwal and Siddique (2014). It is observed from Fig. 13 that the bright and dark matter stands for calcium-silicate-hydrate (C-S-H) gel present inner aggregates during subsequent curing process and acting as a binder in the paste thus improving mechanical properties. Some places the voids and pores are also visible along with salt accumulation marked by white spots. In due process C-S-H gels are formed during hardening process and voids are eliminated therefore strength gains. In SWC samples after 28 days of NWC, the formation of C-S-H gels are hardly visible and salt accumulation is observed in some places by white spots along with voids thus deterioration takes place at later age which are shown in Fig. 14.

6. Durability study

The most external agents are chlorides that intrude into concrete and induced corrosion causing structural damage in marine environments. The carbonation induced corrosion occurred in marine concrete when carbon dioxide intrusion takes place into concrete cover and reaches the reinforcement causing corrosion in presence of moisture and oxygen. In this article the durability

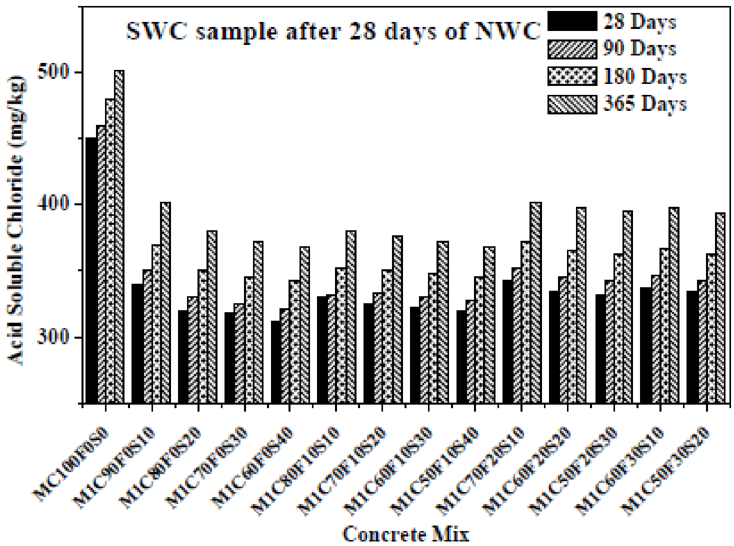

Fig. 15 ASC (mg/kg) versus concrete mix

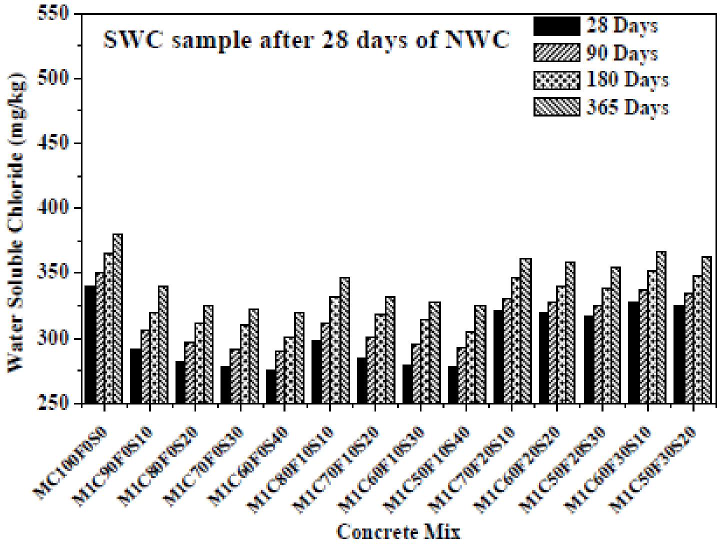

Fig. 16 WSC (mg/kg) versus concrete mix

property in terms of chloride content is presented for SWC precast concrete samples at 28, 90, 180 and 365 days. The WSC and ASC are determined as per IS 14959 - 2001 (Part-1I). The limitations of chloride content for different types of concrete are provided as per IS 456-2000.

6.1 Chloride content

It is observed from both the chloride content that the value obtained in WSC is less than ASC at all ages. ASC versus concrete mix is given in Fig. 15. It is found that the percentage decrease in

ASC is 24%-26% for samples containing 10% FA and 10-40% silpozz replacement with OPC at 365 days age as compared to control specimen. The percentage decrease in ASC is 19.92%-26% for samples containing 0% FA and 10%-40% replacement of silpozz with OPC at 365 days as compared to control specimen. From the above study it is reported that concrete of binary cementitious system with doses of SP indicates lower chloride content then OPC mix without SP. Fig. 16 represents WSC versus concrete mix from which it is found that concrete containing 10% FA fixed and 10-40% silpozz replaced with OPC performed well as compared to control specimen. The percentage decrease in WSC is 15.80% for concrete containing 0% FA and 40% silpozz replaced with OPC and 14.5% for concrete containing 10% FA with 40% silpozz as compared to control specimen at 365 days. It is found that the combination of FA and silpozz with proper does of SP gives better resistance to chloride in sea water at later ages. It is observed that when silpozz content is increasing, the diffusion of chloride is also decreasing for both the cases. As silpozz is acting as fine filler and fills the pores of concrete with SP in subsequent hardening process as a result of which the diffusion of chloride ion may be less.

6.2 Water absorption test

The 100 mm diameter×50 mm height cylinder after casting were immersed in water for 28 days curing. These specimens were then oven dried for 24 hours at the temperature 110°c until the mass became constant and again weighed. This weight was noted as the dry weight (W_1) of the cylinder. After that the specimen was kept in hot water at 85°c for 3.5 hours. Then this weight was noted as the wet weight (W_2) of the cylinder. Percentage water absorption=$[(W_2-W_1)/W_1]\times 100$ Where, W_1 =Oven dry weight of cylinder in grams W_2=After 3.5 hours wet weight of cylinder in grams. Same procedure was adopted for SWC pre-cast samples. Comparison between two samples such as NWC and SWC pre-cast samples are shown in Fig. 17. The SWC pre-cast samples showed less water absorption than the NWC samples in all mixes. There is a decrease trend when replacement

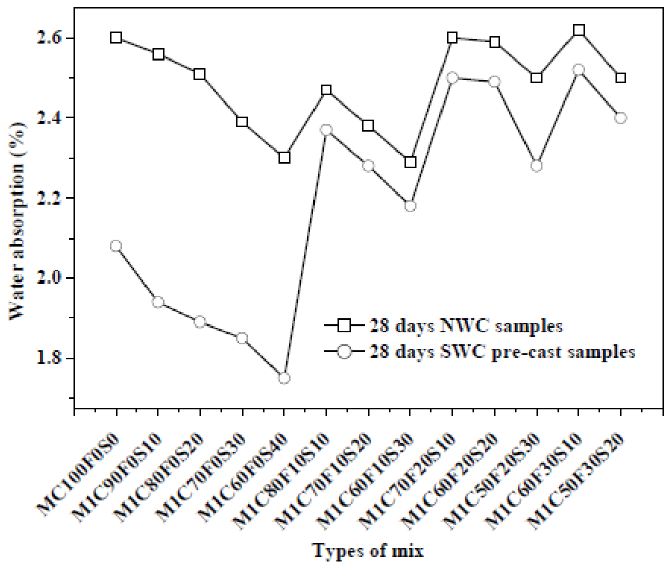

Fig. 17 Water absorption (%) versus concrete mix

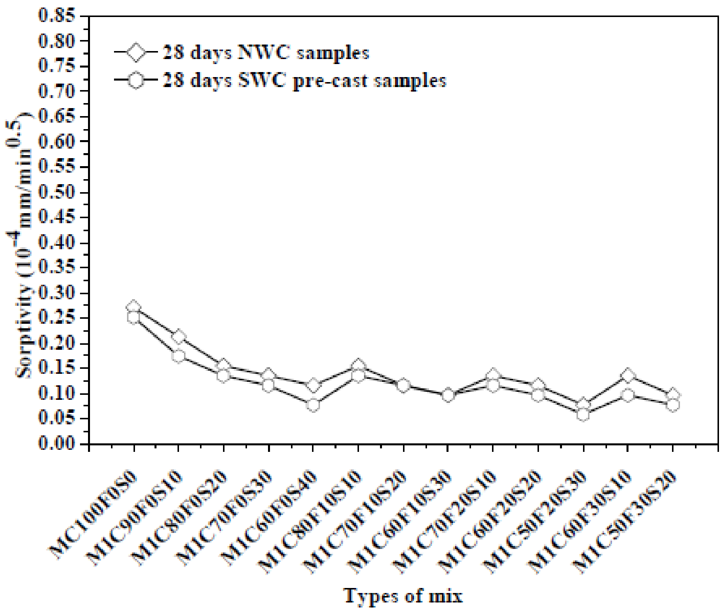

Fig. 18 Sorptivity versus concrete mix

of silpozz increases and increase trend when FA replacement increases. It is observed that with zero FA and silpozz 40% represents minimum water absorption for SWC pre-cast samples.

6.3 Sorptivity test

The sorptivity can be determined by the measurement of the capillary rise absorption rate on reasonably homogeneous material. Water was used of the test fluid. The cylinders after casting were immersed in water for 28 days curing. The specimen size 100 mm diameter and 50 mm height after drying in oven at temperature of 100+10°C were drowned with water level not more than 5 mm above the base of specimen and the flow from the peripheral surface is prevented by sealing it properly with non-absorbent coating. The quantity of water absorbed in time period of 30 minutes was measured by weighing the specimen on a top pan balance weighing upto 0.1 mg. surface water on the specimen was wiped off with a dampened tissue and each weighing operation was completed within 30 seconds. Sorptivity (S) is a material property which characterizes the tendency of a porous material to absorb and transmit water by capillarity.

The cumulative water absorption (per unit area of the inflow surface) increases as the square root of elapsed time (t) $I=S.t^{½}$ therefore $S=I/t^{½}$

Where, S=Sorptivity in mm, t=Elapsed time in min. $I=\Delta w/Ad$, Δw=Change in weight=(W_2−W_1), W_1=Oven dry weight of cylinder in grams, W_2=Weight of cylinder after 30 minutes capillary suction of water in grams, A=Surface area of the specimen through which water penetrated, d=Density of water. The sorptivity versus concrete mix is shown in Fig. 18. It is observed from the Fig. 18 that the sorptivity is less in SWC pre-cast samples than the NWC samples except the samples M1C70F10S20 and M1C60F10S30 which have given equal results. There is also decreasing trend when the percentage replacement of silpozz increasing and when FA replacement is increasing the sorptivity also increasing. It is observed that replacement of silpozz in FA based concrete only restricted the sorptivity and absorption. The SWC pre-cast samples were cured 28 days in normal water and then after they were immersed in sew water for 28 days, therefore these samples have matured stage than the only 28 days NWC samples as well as less sorptivity and absorption capacity than NWC samples.

7. Conclusions

A few conclusions may be drawn from the study:

- Silpozz which is a by-product of rice husk can be utilized with SP as a partial replacement of OPC in cement concrete especially in marine site to improve durability as well as it provides economical, technical and environmental advantages which are very much essential for sustainability in construction sectors.
- Samples of 0% FA and 20% silpozz replaced with OPC contributes higher compressive strength as compared to conventional concrete both in normal water and sea water even at 365 days as the doses of SP is maintained properly. Even the higher dose of SP does not help to increase the early age strength to 365 days age for the sample 30% FA and 20% silpozz as compared to OPC mix.
- It could be concluded from the study that the NWC sample 0% FA and 20% silpozz replaced with OPC possessing compressive strength of 73.50 MPa at 365 days age incorporating with SP but in sea water the pre-cast sample 10% FA and 20% silpozz replaced with OPC gives compressive strength of 69.50 MPa at 365 days age using SP.
- The Deterioration factor (DF) of compressive strength is 3.2% for sea water the pre-cast sample having10% FA and 20% silpozz replaced with OPC at 365 days age when compared to NWC specimen.
- The flexural and split tensile strength is also better at 90 days age for both the samples of NWC and pre-cast SWC samples. As the percentage of FA increases the percentage increase in split tensile strength decreases even higher dose of SP is used at early age.The rate of deterioration of flexural strength is 0.60% for sample 10% FA and 20% silpozz replaced with OPC using SP when compared to SWC samples of same mix at 90 days age but the same sample gives maximum split tensile strength and flexural strength at 90 days among all the samples including control specimen in NWC and SWC conditions.
- The DF of split tensile strength is 1% for SWC pre-cast sample 10% FA and 20% silpozz replaced with OPC using SP when compared to NWC samples at 90 days age.
- As the replacement of cement increases the chloride content increases, when silpozz is incorporated with SP and FA upto 20%, the diffusion of chloride is restricted. The WSC is always less as compared to ASC for each sample and it observed that both ASC and WSC are restricted only for silpozz based concrete with doses of SP.
- It is concluded that silpozz is having average particles size of 25 microns and below, so that it fills the interstices in between the cement in the aggregate as fine filler with the help of SP which gives better strength and resistance to chloride and carbonation.
- In the present study of SEM, the sample M1C70F10S20 with SP showed large formation of C-S-H gel needs for development of dense microstructures. The fibrous C-S-H formation acts as a thick impermeable membrane for the ingress of chloride ion into concrete as well as makes concrete more resistance against aggressive environments.
- The water absorption and sorptivity is restricted when silpozz replacement increases with and

without FA replaced specimens. The SWC pre-cast samples performed better at all levels.
• The addition of SCM such as FA and silpozz with SP enhances the homogeneity of cement paste and densifies the microstructure of the cement considerably as well as improves the strength and durability properties of marine concrete.

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